NASA TECHNICAL MEMORANDUM

NASA TM X-72619

COPY NO.

NASA TM X- 72619

AERODYNAMIC DAMPING AND OSCILLATORY STABILITY OF A MODEL OF A PROPOSED HL-10 VEHICLE IN PITCH AT MACH NUMBERS FROM 0.20 TO 2.86 AND IN YAW AT MACH NUMBERS FROM 0.20 TO 1.20

By Robert A. Kilgore and Edwin E. Davenport

October 15, 1974

(NASA-TM-X-72619) AERODYNAMIC DAMPING AND OSCILLATORY STABILITY OF A MODEL OF A PROPOSED HL-10 VEHICLE IN PITCH AT MACH NUMBERS FROM 0.20 TO 2.86 AND IN YAW AT MACH NUMBERS FROM 0.20 TO 1.20 (NASA) 41 p HC G3/02

N75-14713

Unclas 06554

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No. NASA TM X-72619	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle AERODYNAMIC DAMPING AND OSCILLATORY STABILITY OF A MODEL OF A PROPOSED HL-10 VEHICLE IN PITCH AT MACH NUMBERS FROM 0.20 TO 2.86 AND IN YAW AT MACH NUMBERS FROM 0.20 TO 1.20

5. Report Date October 15, 1974

6. Performing Organization Code

7. Author(s)
Robert A. Kilgore and Edwin E. Davenport

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Virginia 23665

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D. C. 20546

13. Type of Report and Period Covered High-Number TM X

14. Sponsoring Agency Code

15. Supplementary Notes

Final release of special information not suitable for formal publication.

16. Abstract

Wind-tunnel tests were made at angles of attack from -2° to 21° at Mach numbers from 0.20 to 1.20 and at angles of attack from near 0° to about 28° at Mach numbers of 1.80, 2.16, and 2.86. The tests were made at 0° angle of sideslip by using a small-amplitude forced-oscillation technique.

The results of the investigation indicate that at subsonic and transonic speeds, the configuration has slightly positive damping in pitch except at the higher angles of attack at Mach numbers of 0.80, 0.90, and 1.00. At supersonic speeds the configuration has positive damping in pitch for all test conditions. Positive stability is present for all test conditions except at $M = 1.80$ at an angle of attack of 26° where the configuration is very unstable with greatly increased positive damping. At subsonic and transonic speeds, the configuration has positive damping in yaw and positive stability in yaw for all test conditions.

17. Key Words (Suggested by Author(s)) (STAR category underlined)	18. Distribution Statement
Aerodynamics, aerodynamic damping, oscillatory stability, and lifting body	Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	37	$3.75

*Available from { The National Technical Information Service, Springfield, Virginia 22151
STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AERODYNAMIC DAMPING AND OSCILLATORY STABILITY OF A MODEL OF A PROPOSED HL-10 VEHICLE IN PITCH AT MACH NUMBERS FROM 0.20 to 2.86 AND IN YAW AT MACH NUMBERS FROM 0.20 to 1.20

By Robert A. Kilgore and Edwin E. Davenport

ABSTRACT

Wind-tunnel tests were made at angles-of-attack from -2° to 21° at Mach numbers from 0.20 to 1.20 and at angles-of-attack from near 0° to about 28° at Mach numbers of 1.80, 2.16, and 2.86. The tests were made at 0° angle-of-sideslip by using a small-amplitude forced-oscillation technique.

The results of the investigation indicate that at subsonic and transonic speeds, the configuration has slightly positive damping in pitch except at the higher angles of attack at Mach numbers of 0.80, 0.90, and 1.00. At supersonic speeds the configuration has positive damping in pitch for all test conditions. The configuration has positive static longitudinal stability for all test conditions except at $M = 1.80$ at an angle of attack of 26° where it becomes very unstable but exhibits a high degree of positive damping. At subsonic and transonic speeds, the configuration has positive damping in yaw and positive stability in yaw for all test conditions.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AERODYNAMIC DAMPING AND OSCILLATORY STABILITY OF A MODEL OF A PROPOSED HL-10 VEHICLE IN PITCH AT MACH NUMBERS FROM 0.20 TO 2.86 AND IN YAW AT MACH NUMBERS FROM 0.20 TO 1.20

By Robert A. Kilgore and Edwin E. Davenport

SUMMARY

Wind-tunnel measurements of the aerodynamic damping and oscillatory stability in pitch and yaw of a sub-scale model of a proposed HL-10 configuration have been made at 0° angle of sideslip by using a small-amplitude forced-oscillation technique. The damping and oscillatory stability parameters in both pitch and yaw were measured at Mach numbers from 0.20 to 1.20 at angles-of-attack from -2° to about 21°. The parameters in pitch also were obtained at Mach numbers of 1.80, 2.16, and 2.86 at angles-of-attack from near 0° to about 28°. Reynolds number was about 3.4×10^6 at Mach numbers from 0.20 to 1.20 and about 2.9×10^6 at Mach numbers of 1.80, 2.16, and 2.86. The reduced-frequency parameter varied from 0.0102 to 0.0784 for the tests in pitch and from 0.0084 to 0.0438 for the tests in yaw.

The results of the investigation indicate that at subsonic and transonic speeds, the configuration has slightly positive damping in pitch except at the higher angles of attack at Mach numbers of 0.80, 0.90, and 1.00. The configuration also has positive stability in pitch except for limited regions of instability at Mach numbers of 0.60, 0.80, and 0.90. At supersonic speeds, the configuration has positive damping in pitch for all test conditions. The configuration has positive static longitudinal stability for all test conditions except at $M = 1.80$ at an angle of attack of 26° where it becomes very unstable

but exhibits a high degree of positive damping. At subsonic and transonic speeds, the configuration has positive damping in yaw and positive stability in yaw for all test conditions.

INTRODUCTION

The National Aeronautics and Space Administration is involved in investigations of the flight and landing characteristics of several configurations of manned lifting vehicles capable of entering the earth's atmosphere. Early studies indicated that vehicles with maximum hypersonic lift-drag ratios of about 1 and subsonic lift-drag ratios sufficient to allow a conventional glide landing appear to be capable of meeting requirements. As part of this reasearch program, studies were made of the aerodynamic characteristics associated with this class of vehicle in atmospheric flight over the anticipated speed and angle-of-attack ranges. One configuration which was proposed, studied, and developed in the program has negative camber and is designated HL-10 (Horizontal Lander 10).

The HL-10 configuration of reference 1 had vertical tip fins which provided adequate directional stability at a Mach number of 6.8. However, as reported in reference 2, at subsonic speeds the tip fins were subject to local flow separation and were ineffective in providing the vehicle with adequate directional stability. As reported in reference 2, it was found that addition of a center vertical fin provided increased directional stability at subsonic speeds. In addition, the tip fins were canted outboard to provide increased directional stability at hypersonic speeds. The static aerodynamic characteristics of a model of this revised HL-10 configuration at low speeds are presented in references 3 and 4. The results of wind-tunnel tests to determine

the longitudinal and directional damping and oscillatory stability of a model of an HL-10 configuration at Mach numbers from 0.20 to 1.00 are presented in reference 5.

This paper presents the results of wind tunnel tests which were made to determine the damping and stability parameters for a sub-scale model of the HL-10 configuration at Mach numbers from 0.20 to 2.86. The damping and stability parameters in both pitch and yaw were obtained at Mach numbers from 0.20 to 1.20 at angles-of-attack from about -2° to 21°. The parameters in pitch also were obtained at Mach numbers of 1.80, 2.16, and 2.86 at angles-of-attack from near 0° to about 28°. The tests were made at 0° angle-of-sideslip at an oscillation amplitude of about 1° by using a forced-oscillation technique. The results of these tests were obtained in the Langley 8-foot transonic pressure tunnel and the Langley Unitary Plan wind tunnel.

SYMBOLS

Measurements and calculations for the investigation were made and are given in the International System of Units (SI). Details concerning the use of SI, together with physical constants and conversion factors, are given in reference 6.

The aerodynamic parameters are referred to the body system of axes, as shown in figure 1, in which the coefficients, angles, and angular velocities are shown in the positive sense. These axes originate at the center of moments of the model as shown in figure 2. The equations used to reduce the data are presented in the section on "Procedure and Reduction of Data."

A	reference area, 0.1114 m^2

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty Ad}$ (see fig. 1)

$C_{m_q} = \frac{\partial C_m}{\partial \frac{qd}{2V}}$ per radian

$C_{m_{\dot{q}}} = \frac{\partial C_m}{\partial \left(\frac{\dot{q}d^2}{4V^2}\right)}$ per radian

$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$ per radian

$C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial \left(\frac{\dot{\alpha}d}{2V}\right)}$ per radian

$C_{m_q} + C_{m_{\dot{\alpha}}}$ damping-in-pitch parameter, per radian

$C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ oscillatory-longitudinal-stability parameter, per radian

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{q_\infty Ad}$ (see fig. 1)

$C_{n_r} = \frac{\partial C_n}{\partial \left(\frac{rd}{2V}\right)}$ per radian

$C_{n_{\dot{r}}} = \frac{\partial C_n}{\partial \left(\frac{\dot{r}d^2}{4V^2}\right)}$ per radian

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$ per radian

$C_{n_{\dot{\beta}}} = \frac{\partial C_n}{\partial \left(\frac{\dot{\beta}d}{2V}\right)}$ per radian

$C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ damping-in-yaw parameter, per radian

$C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$ oscillatory-directional-stability parameter, per radian

d reference length, 0.5587m for pitch tests, 0.3606m for yaw tests

f frequency of oscillation, hertz

k reduced-frequency parameter, $\frac{\omega d}{2V}$, radians

M free-stream Mach number

q angular velocity of model about Y-axis, radians/second (see fig. 1)

q_∞ free-stream dynamic pressure, N/m^2

R Reynolds number based on reference length for pitch tests, 0.5587m

r angular velocity of model about Z-axis, radians/second (see fig. 1)

V free-stream velocity, m/s

X,Y,Z body system of axis (see fig. 1)

α angle-of-attack, degrees or radians or mean angle-of-attack, degrees (see fig. 1)

β angle-of-sideslip, radians (see fig. 1)

ω angular velocity, $2\pi f$, radians/second

A dot over a quantity denotes the first derivative with respect to time. The expression $\cos \alpha$ appears in the damping-in-yaw and oscillatory-directional-stability parameters because these parameters are expressed in the body system of axes.

APPARATUS

Model

Design dimensions of the model of the proposed HL-10 configuration tested are presented in figure 2. The model was geometrically similar to the proposed HL-10 configuration except for the aft portion which was modified to provide clearance for the model-support sting. Photographs of the model are presented in figure 3. The model was made of magnesium and all surfaces exposed to the airstream were aerodynamically smooth.

Oscillation - Balance Mechanism

A view of the forward portion of the oscillation-balance mechanism which was used for these tests is presented in figure 4. The location of the torque bridge between the model-attachment surface and the pivot axis eliminates the effects of pivot friction and the necessity to correct the data for the changing pivot friction associated with changing aerodynamic loads. A mechanical spring, which is an integral part of the fixed balance support, is connected to the oscillation balance at the point of model attachment by means of a flexure plate. A strain-gage bridge, fastened to the mechanical spring, provides a signal proportional to the model angular displacement with respect to the sting.

Wind Tunnels

Two wind tunnels were used to obtain the data presented herein. Both tunnels are equipped for control of relative humidity of the air in order to minimize the effects of condensation shocks. Also, total temperature and total pressure can be varied to obtain the desired test Reynolds number.

Langley 8-foot transonic pressure tunnel.- The data for Mach numbers from 0.20 to 1.20 were obtained in the Langley 8-foot transonic pressure tunnel. The test section of this single-return wind tunnel is about 2.2 meters square with slotted upper and lower walls to permit continuous operation through the transonic speed range. Test-section Mach numbers from about 0.20 to 1.30 can be obtained and kept constant by controlling the speed of the tunnel-fan drive motor.

The sting-support strut is designed to keep the model near the center line of the tunnel through the range of angle-of-attack. A more detailed description of the Langley 8-foot transonic pressure tunnel is given in reference 7.

Langley Unitary Plan wind tunnel.- The data for Mach numbers of 1.80, 2.16, and 2.86 were obtained in test section number 1 of the Langley Unitary Plan wind tunnel. This single return tunnel has a test section about 1.2 meters square and about 2.1 meters long. An asymmetric sliding block, which varies the area ratio, is used to change the Mach number from about 1.47 to 2.86. A more detailed description of the Langley Unitary Plan wind tunnel is given in reference 7.

PROCEDURE AND REDUCTION OF DATA

For the pitching tests, measurements are made of the amplitude of the torque required to oscillate the model in pitch T_Y, the amplitude of the angular displacement in pitch of the model with respect to the sting θ, the phase angle η between T_Y and θ, and the angular velocity of the forced oscillation ω. Some details of the electronic instrumentation used to make these measurements are given in reference 8. The viscous-damping coefficient in

pitch C_Y for this single-degree-of-freedom system is computed as

$$C_Y = \frac{T_Y \sin \eta}{\omega \theta}$$

and the spring-inertia parameter in pitch is computed as

$$K_Y - I_Y\omega^2 = \frac{T_Y \cos \eta}{\theta}$$

where K_Y is the torsional-spring coefficient of the system and I_Y is the moment of inertia of the system about the body Y-axis.

The damping-in-pitch parameter was computed as

$$C_{m_q} + C_{m_{\dot{\alpha}}} = -\frac{2V}{q_\infty Ad^2} \left| \left(C_Y\right)_{\text{wind on}} - \left(C_Y\right)_{\text{wind off}} \right|$$

and the oscillatory-longitudinal-stability parameter was computed as

$$C_{m_\alpha} - k^2 C_{m_{\dot{q}}} = -\frac{1}{q_\infty Ad} \left[\left(K_Y - I_Y\omega^2\right)_{\text{wind on}} - \left(K_Y - I_Y\omega^2\right)_{\text{wind off}}\right]$$

Since the wind-off value of C_Y is not a function of oscillation frequency, it is determined at the frequency of wind-off velocity resonance because C_Y can be determined most accurately at this frequency. The wind-off value of $K_Y - I_Y\omega^2$ is determined at the same frequency as the wind-on value of $K_Y - I_Y\omega^2$ since this parameter is a function of frequency.

For the yawing tests, measurements are made of the amplitude of the torque required to oscillate the model in yaw T_Z, the amplitude of the angular

displacement in yaw of the model with respect to the sting Ψ, the phase angle λ between T_Z and Ψ, and the angular velocity of the forced oscillation ω. The viscous-damping coefficient in yaw C_Z for this single-degree-of-freedom system is computed as

$$C_Z = \frac{T_Z \sin \lambda}{\omega \Psi}$$

and the spring-inertia parameter in yaw is computed as

$$K_Z - I_Z\omega^2 = \frac{T_Z \cos \lambda}{\Psi}$$

where K_Z is the torsional-spring coefficient of the system and I_Z is the moment of inertia of inertia of the system about the body Z-axis.

For these tests, the damping-in-yaw parameter was computed as

$$C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha = -\frac{2V}{q_\infty A d^2}\left[\left(C_Z\right)_{\text{wind on}} - \left(C_Z\right)_{\text{wind off}}\right]$$

and the oscillatory-directional-stability parameter was computed as

$$C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}} = \frac{1}{q_\infty A d}\left[\left(K_Z - I_Z\omega^2\right)_{\text{wind on}} - \left(K_Z - I_Z\omega^2\right)_{\text{wind off}}\right]$$

The wind-off value of C_Z is determined at the frequency of wind-off velocity resonance, and the wind-off and wind-on values of $K_Z - I_Z\omega^2$ are determined at the same frequency.

TEST CONDITIONS

The damping and oscillatory stability parameters in both pitch and yaw were obtained at Mach numbers from 0.20 to 1.20 at angles-of-attack from -2° to about 21° at 0° angle-of-sideslip. The parameters in pitch also were obtained at Mach numbers of 1.80, 2.16, and 2.86 at angles-of-attack from near 0° to about 28°. Reynolds number, based on a reference length of 0.5587 meters, stagnation pressure, and stagnation temperature for the various Mach numbers were as follows:

Mach number, M	Stagnation pressure, kN/m^2	Stagnation temperature, K	Reynolds number, R
2.86	77.1×10^4	339	2.86×10^6
2.16	53.7	339	2.87
1.80	46.4	339	2.91
1.20	45.3	324	3.42
1.00	46.1	322	3.42
.90	48.4	321	3.50
.80	50.5	321	3.45
.60	60.4	320	3.48
.40	80.0	318	3.38
.20	149.7	317	3.35

The data were obtained at an oscillation amplitude of about 1° (one half of peak to peak) with the model-balance system oscillating at or near the frequency of velocity resonance. The frequency of oscillation varied from 3.02 to 8.80

hertz. The reduced-frequency paraemter, $\frac{\omega d}{2V}$, varied from 0.0102 to 0.0784 for the tests in pitch and from 0.0084 to 0.0438 for the tests in yaw. The tests were made with an aerodynamically smooth model.

DATA CORRECTIONS AND PRECISION

Tunnel-wall and model-support interference effects were assumed to be negligible and no corrections for these effects were made to the data. The values of angle-of-attack, α, have been corrected for flow angularity in the test section as follows:

Mach number, M	Flow angularity correction, deg.
2.86	0
2.16	1.38
1.80	0.60
0.20 to 1.20	0.20

These corrections apply strictly only for a model at the vertical center of the test section, however, the corrections were applied to all of the data as a first-order correction to α. For the data presented herein, values of the probable error of the various quantities are as follows:

Quantity	Probable error for—	
	M = 0.20 to 1.20	M = 1.80 to 2.86
Mach number, M	±0.002	±0.002
Mean angle-of-attack or angle-of-attack, α, deg.	±0.1	±0.3
Reynolds number, R	$\pm 0.01 \times 10^6$	$\pm 0.002 \times 10^6$
Damping-in-pitch parameter, $C_{m_q} + C_{m_{\dot{\alpha}}}$, per radian	±0.2	±0.2
Oscillatory-longitudinal-stability parameter, $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$, per radian	±0.01	±0.01
Damping-in-yaw parameter, $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$, per radian	±0.4	------
Oscillatory-directional-stability parameter, $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$, per radian	±0.02	------
Reduced-frequency parameter, k, radians	±0.0003	±0.0003

TEST RESULTS

The results of these tests are presented graphically as follows:

Mach number M	Longitudinal results	Lateral results
0.20	Fig. 5(a)	Fig. 7(a)
.40	5(b)	7(b)
.60	5(c)	7(c)
.80	5(d)	7(d)
.90	5(e)	7(e)
1.00	5(f)	7(f)
1.20	5(g)	7(g)
1.80	6(a)	----
2.16	6(b)	----
2.86	6(c)	----

Positive damping-in-pitch and positive oscillatory stability-in-pitch are indicated by negative values of $C_{m_q} + C_{m_{\dot{\alpha}}}$ and $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ respectively. Positive damping in yaw is indicated by negative values of $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ while positive oscillatory stability in yaw is indicated by positive values of $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$.

Typical schlieren photographs obtained at Mach numbers of 1.80, 2.16, and 2.86 are presented as figure 8.

Longitudinal Results

The data presented in figure 5 indicates that the HL-10 configuration has slightly positive damping in pitch except at the higher values of α at $M = 0.80$, 0.90, and 1.00. The configuration also has positive oscillatory stability in pitch except for limited regions of instability at $M = 0.60$, 0.80, and 0.90. These results are in general agreement with the results presented in reference 5 which were obtained on a geometrically similar model approximately 1.4 times the scale of the model used for these tests. (In comparing the results presented herein with the results of reference 5, due account must be taken of the definition of angle-of-attack. $\alpha = 0^\circ$ of reference 5 corresponds to $\alpha = 6.5^\circ$ for the results of this report.)

The data presented in figure 6 indicates that the HL-10 configuration has positive damping in pitch for all test conditions at supersonic speeds. The large amount of positive damping present at $M = 1.80$ at α 26° is in good agreement with unpublished results obtained for a similar configuration at these test conditions. The configuration has positive oscillatory stability for all test conditions except at $M = 1.80$ at α 26° where the model is very unstable. This trend is also in agreement with the unpublished results previously mentioned. The two schlieren photographs presented at $M = 1.80$ in figure 8(a) indicate that two grossly different flow conditions were present as the model was being oscillated $\pm 1^\circ$ about the mean angle-of-attack position of 26°. This unstable flow condition appears to cause the large increases in positive damping and directional instability.

Directional Results

The subsonic and transonic results presented in figure 7 show that the HL-10 configuration has positive damping in yaw and positive oscillatory stability in yaw for all test conditions.

CONCLUDING REMARKS

Wind-tunnel measurements have been made of the aerodynamic damping and oscillatory stability in pitch and yaw for a sub-scale model of a proposed HL-10 configuration by using a 1°-amplitude forced-oscillation mechanism. The parameters in both pitch and yaw were measured at Mach numbers from 0.20 to 1.20 at angles-of-attack, α, from -2° to about 21°. The parameters in pitch also were measured at Mach numbers of 1.80, 2.16, and 2.86 at α's from near 0° to about 28°.

At subsonic and transonic speeds, the configuration has slightly positive damping in pitch except at the higher α's at $M = 0.80$, 0.90, and 1.00. The configuration also has positive stability in pitch except for limited regions of instability at $M = 0.60$, 0.80, and 0.90.

The configuration has positive static longitudinal stability for all test conditions except at $M = 1.80$ at an angle of attack of 26° where it becomes very unstable but exhibits a high degree of positive damping.

At subsonic and transonic speeds the configuration has positive damping in yaw and positive stability in yaw for all test conditions.

REFERENCES

1. Rainey, Robert W., and Ladson, Charles L.: Preliminary Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 6.8. NASA TM X-844, 1963.

2. Ware, George M.: Aerodynamic Characteristics of Models of Two Thick 74° Delta Manned Lifting Entry Vehicles at Low-Subsonic Speeds. NASA TM X-914, 1964.

3. Ware, George M.: Full-Scale Wind-Tunnel Investigation of the Aerodynamic Characteristics of the HL-10 Manned Lifting Entry Vehicle. NASA TM X-1160, 1965.

4. Spencer, Bernard, Jr,; and Fox, Charles H., Jr.: Subsonic Longitudinal Control Characteristics of Several Elevon Configurations for a Manned Lifting Entry Vehicle. NASA TM X-1227, 1966.

5. Wiley, Harleth G.; and Brower, Margaret L.: Damping and Oscillatory Stability in Pitch and Yaw for a Model of an HL-10 Configuration at Mach Numbers From 0.20 to 1.00. NASA TM X-1467, 1967.

6. Mechtley, E. A.: The International System of Units-Physical Constants and Conversion Factors-Second Revision. NASA SP-7012, 1973.

7. Schaefer, William T., Jr.: Characteristics of Major Active Wind Tunnels at the Langley Research Center. NASA TM X-1130, 1965.

8. Wright, Bruce R.; and Kilgore, Robert A.: Aerodynamic Damping and Oscillatory Stability in Pitch and Yaw of Gemini configuration at Mach numbers from 0.50 to 4.63. NASA TN D-3334, 1966.

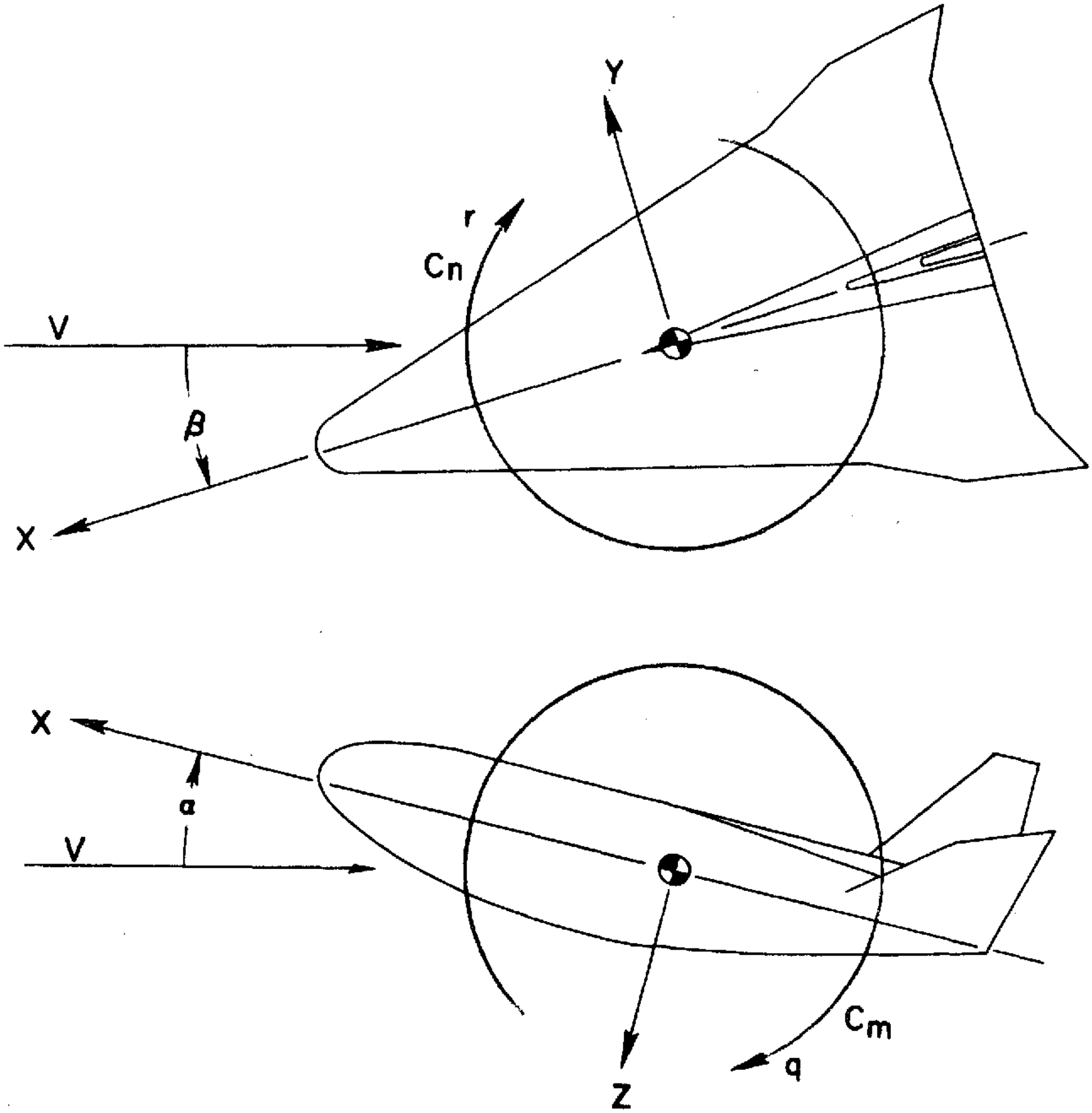
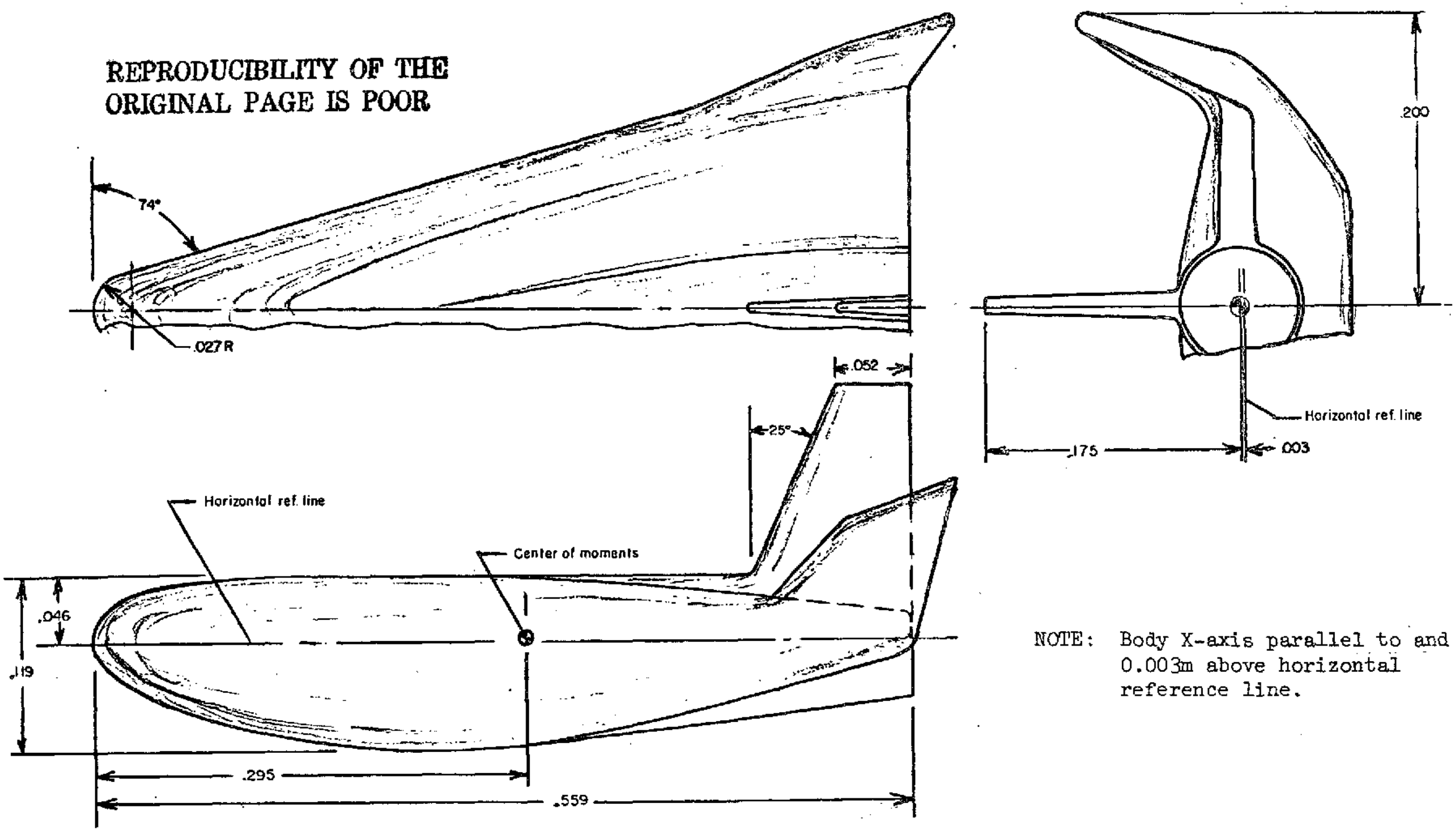


Figure 1.- Body system of axes. Coefficients, angles and angular velocities shown in positive sense.



NOTE: Body X-axis parallel to and 0.003m above horizontal reference line.

Figure 2.- Design dimensions of model. All dimensions in meters.

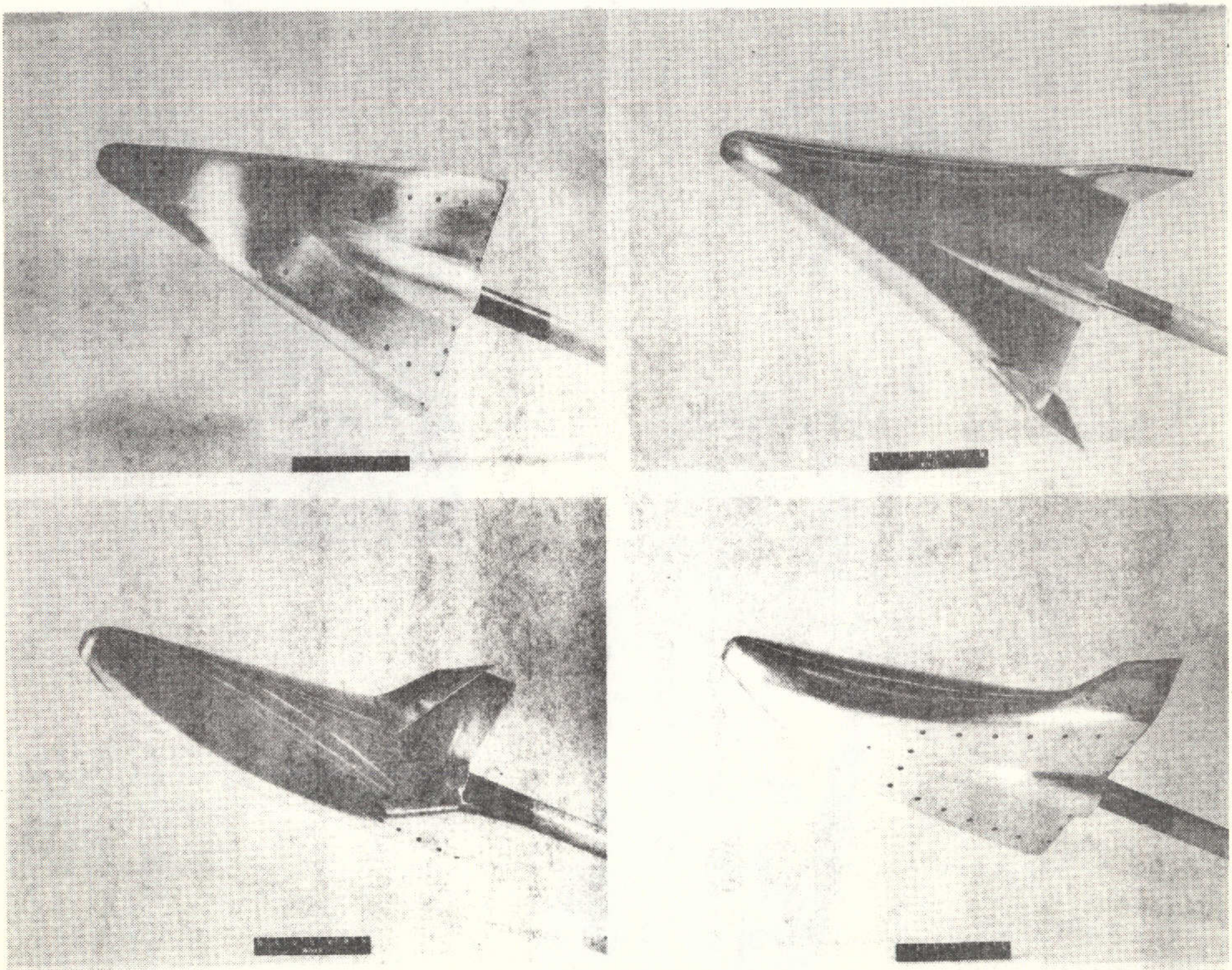


FIGURE 3. - PHOTOGRAPHS OF MODEL

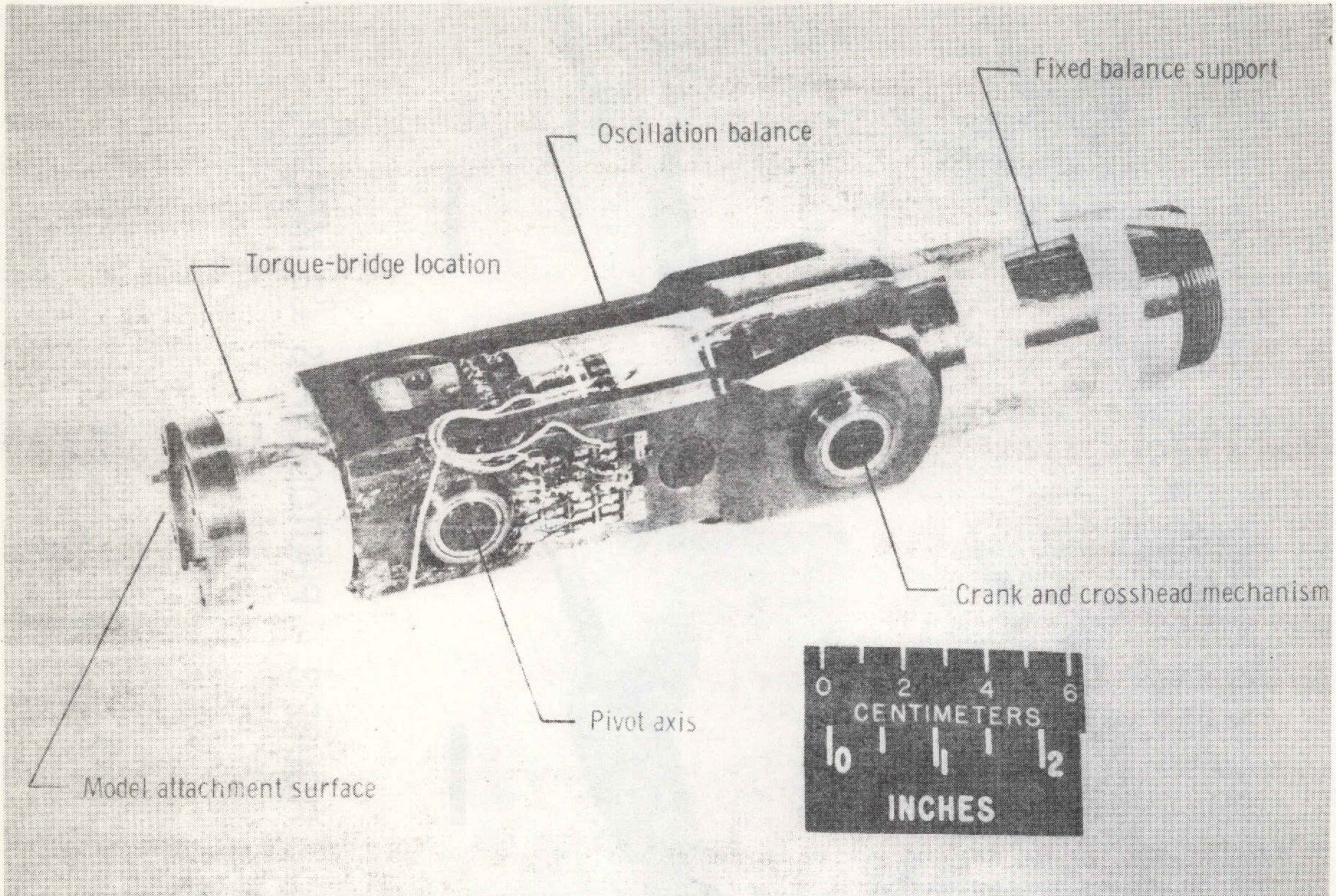
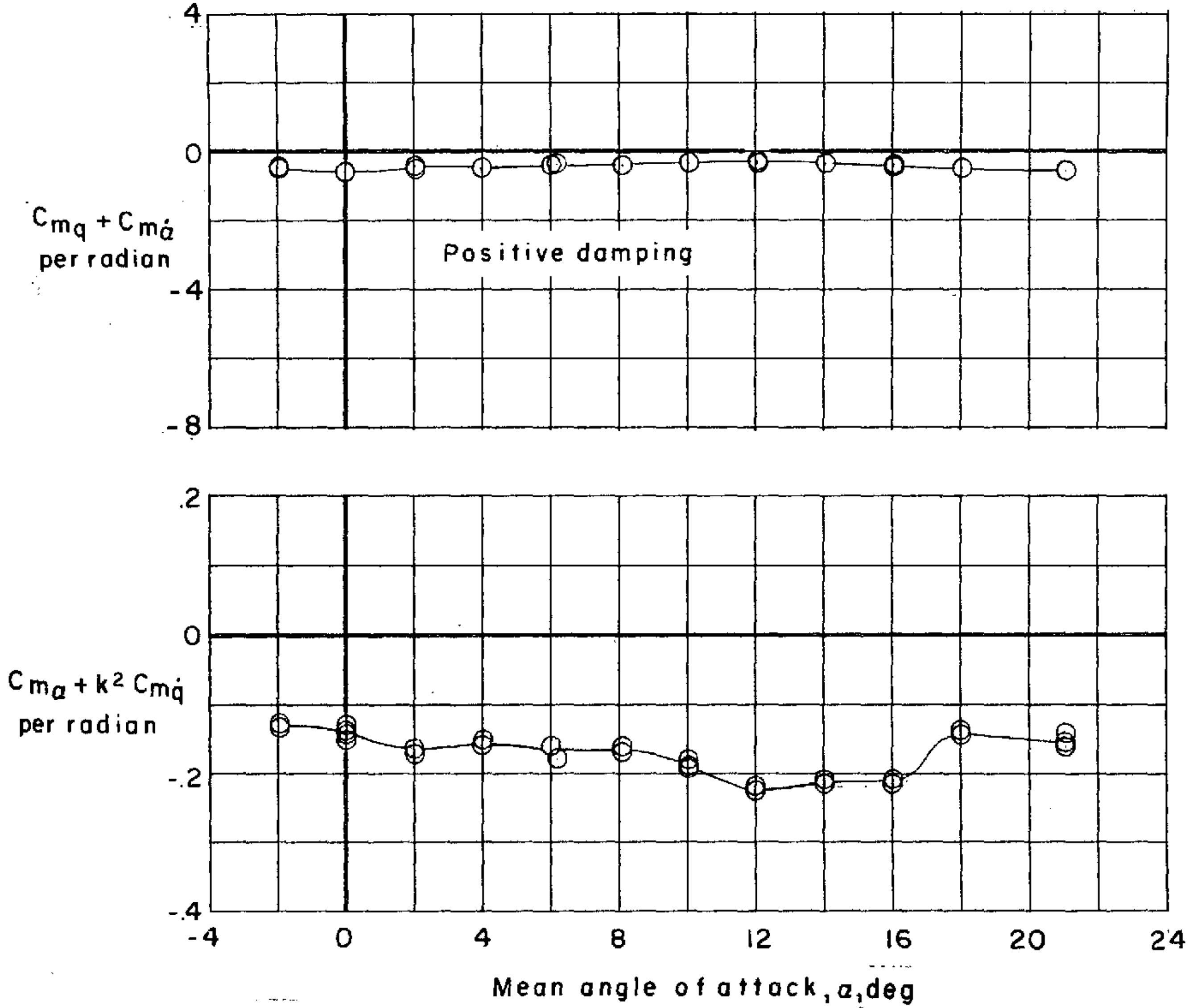
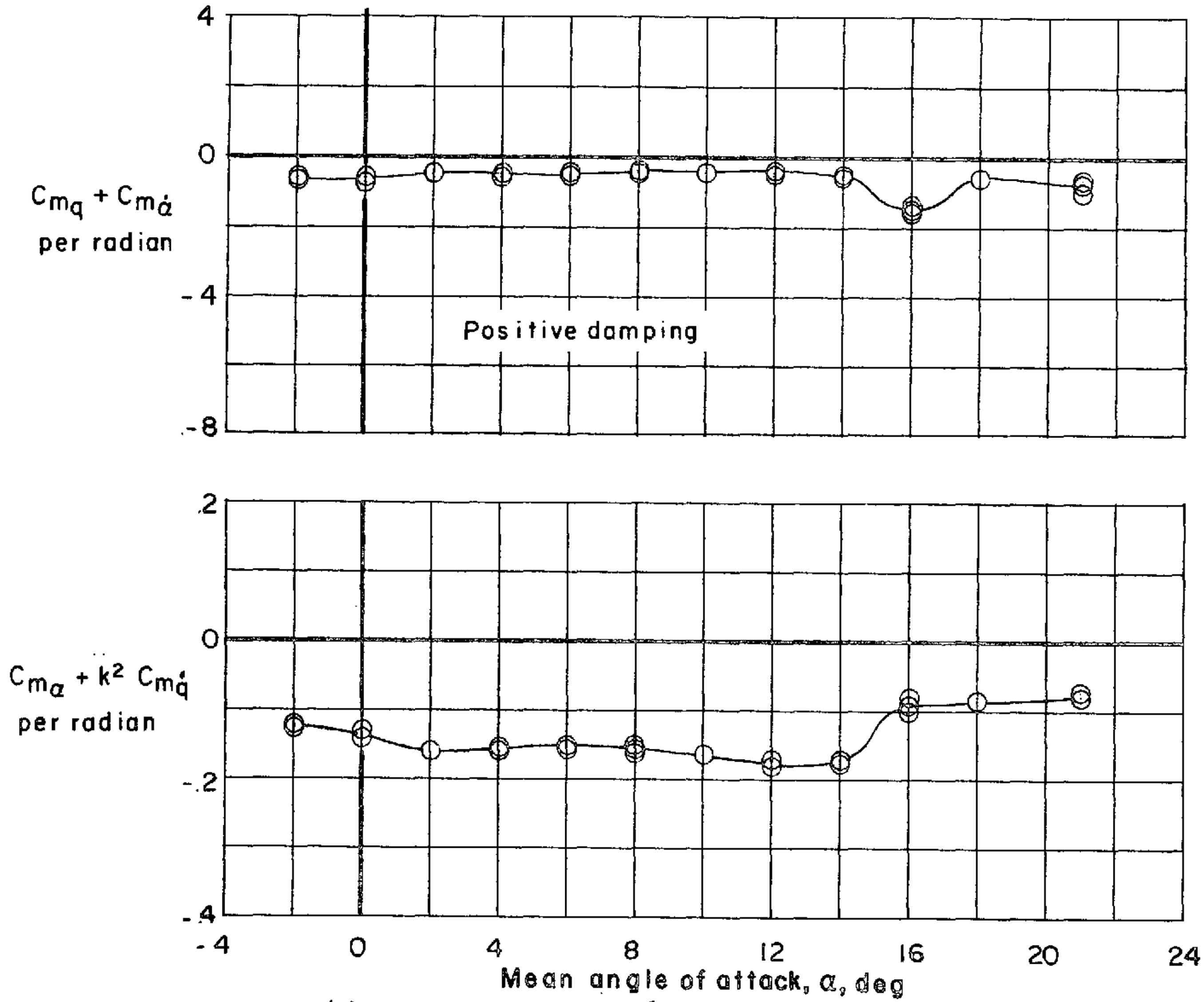


Figure 4.- Forward portion of oscillation - balance mechanism.



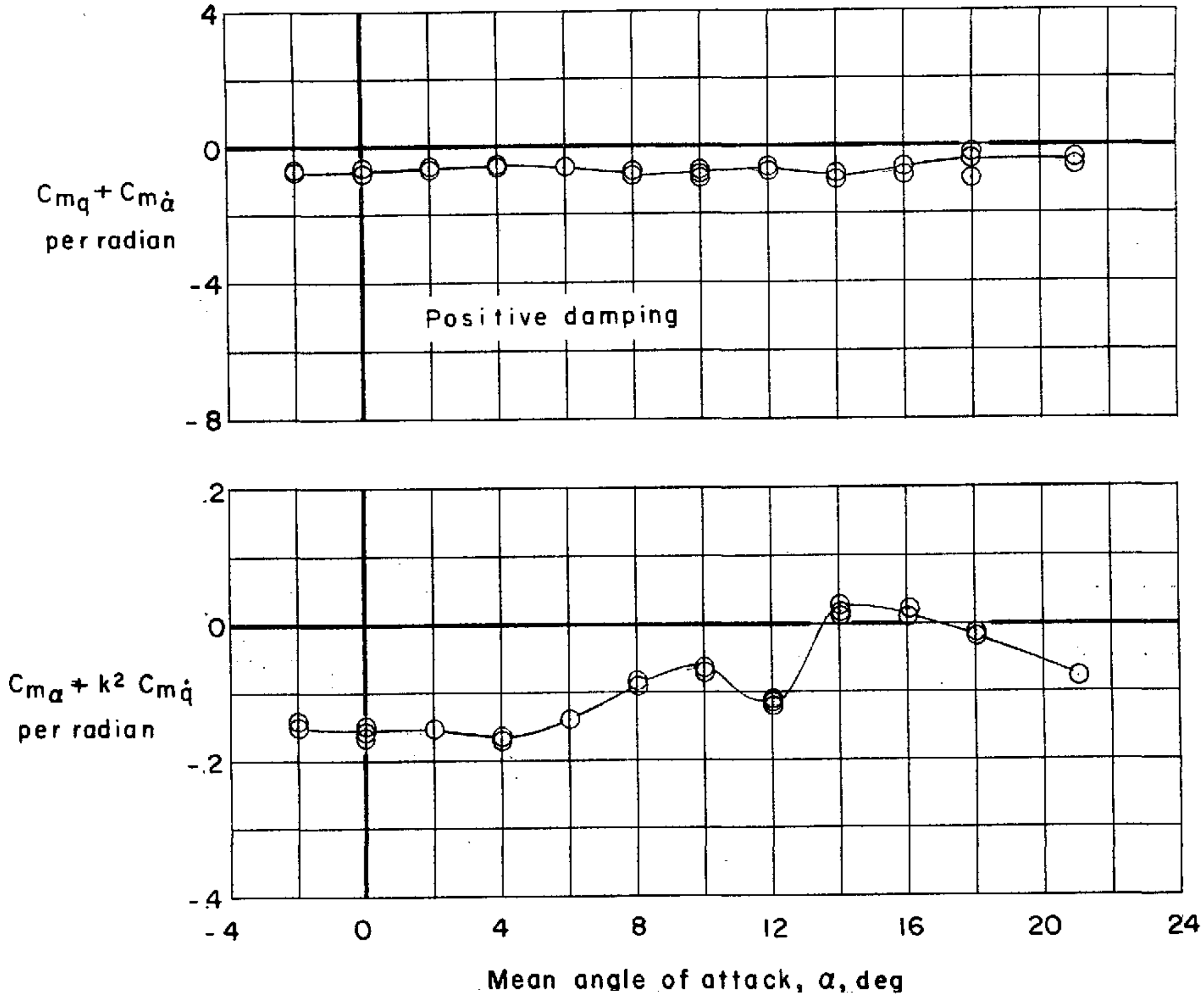
(a) $M = 0.20$, $R = 3.35 \times 10^6$, $k = .0752$ to $.0784$

Figure 5.- Variation of damping-in-pitch and oscillatory-longitudinal-stability parameters with mean angle of attack for a model of a proposed HL-10 configuration at Mach numbers from 0.20 to 1.20.



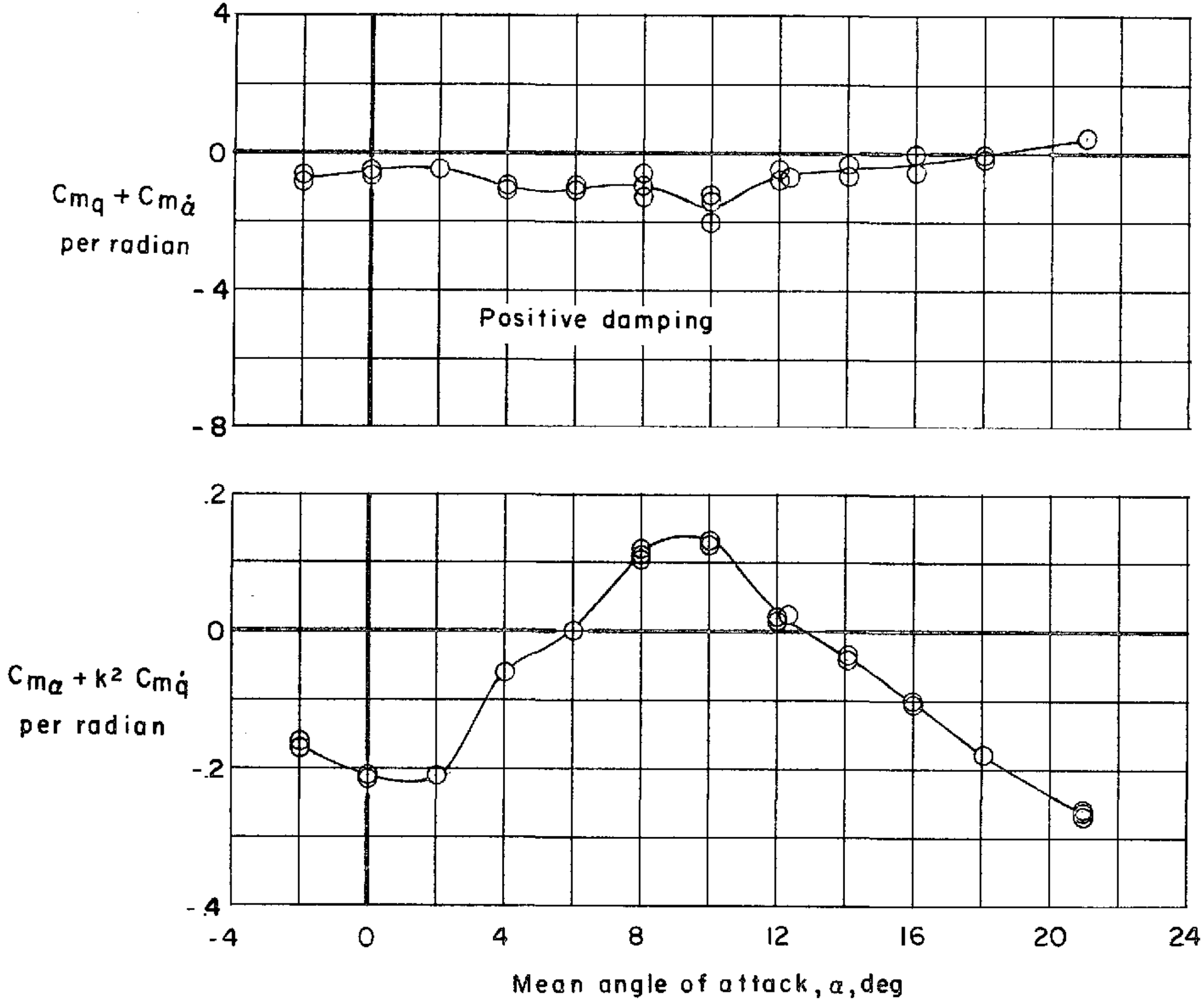
(b) $M = 0.40$, $R = 3.38 \times 10^6$, $k = .0382$ to $.0419$

Figure 5.- Continued.



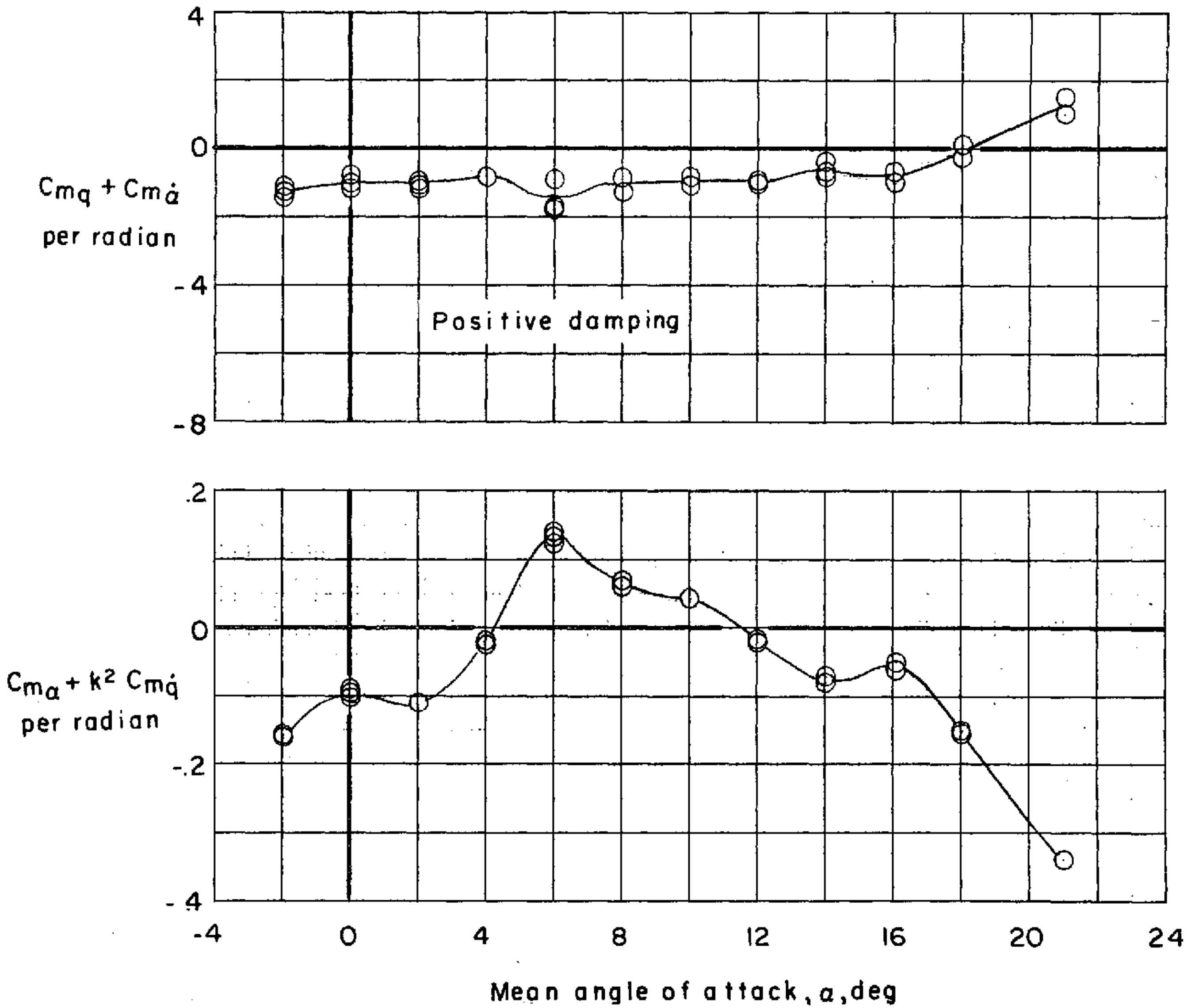
(c) $M = 0.60$, $R = 3.48 \times 10^6$, $k = .0234$ to $.0296$

Figure 5.- Continued.



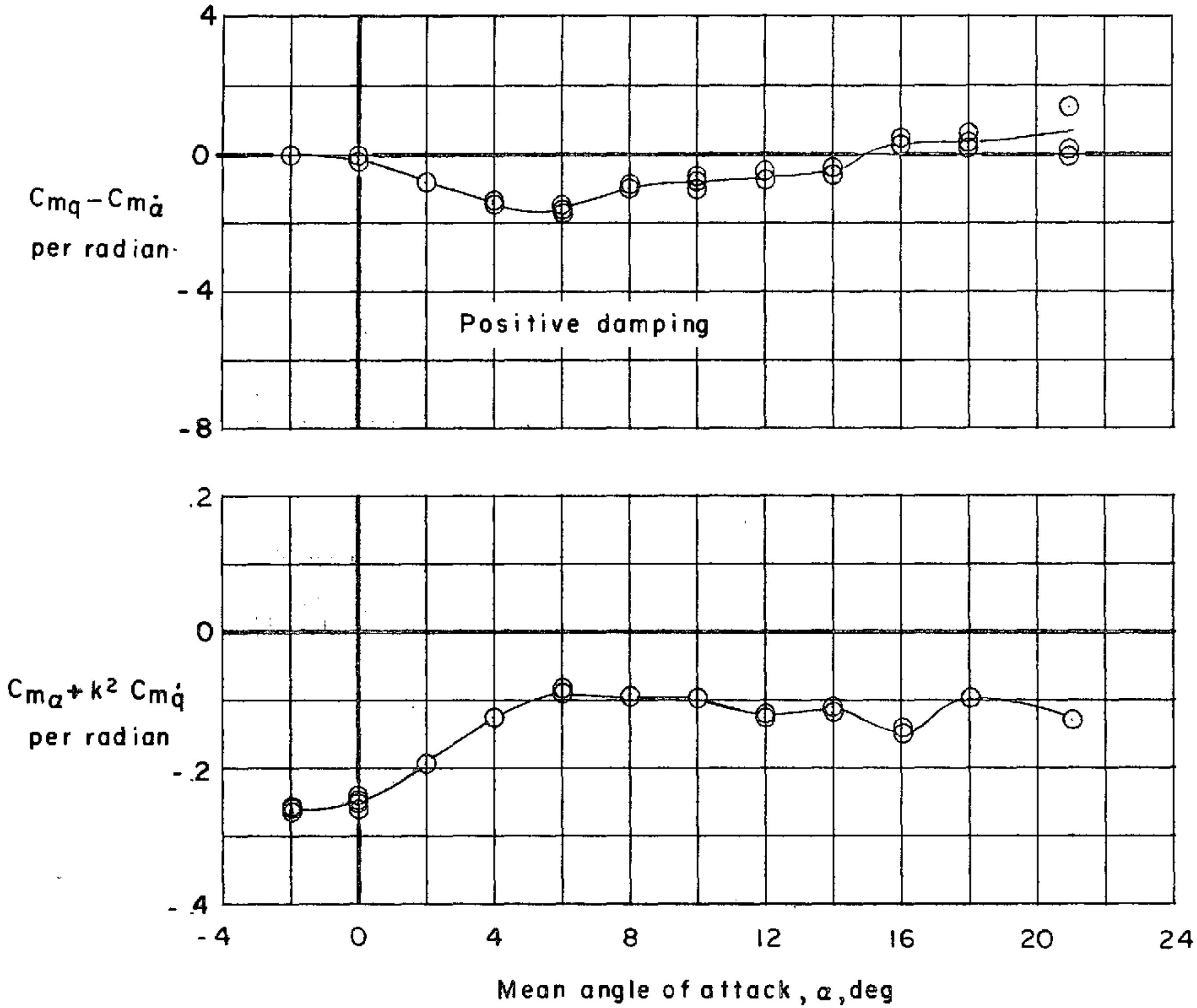
(d) $M = 0.80$, $R = 3.45 \times 10^6$, $k = .0139$ to $.0261$

Figure 5.- Continued.



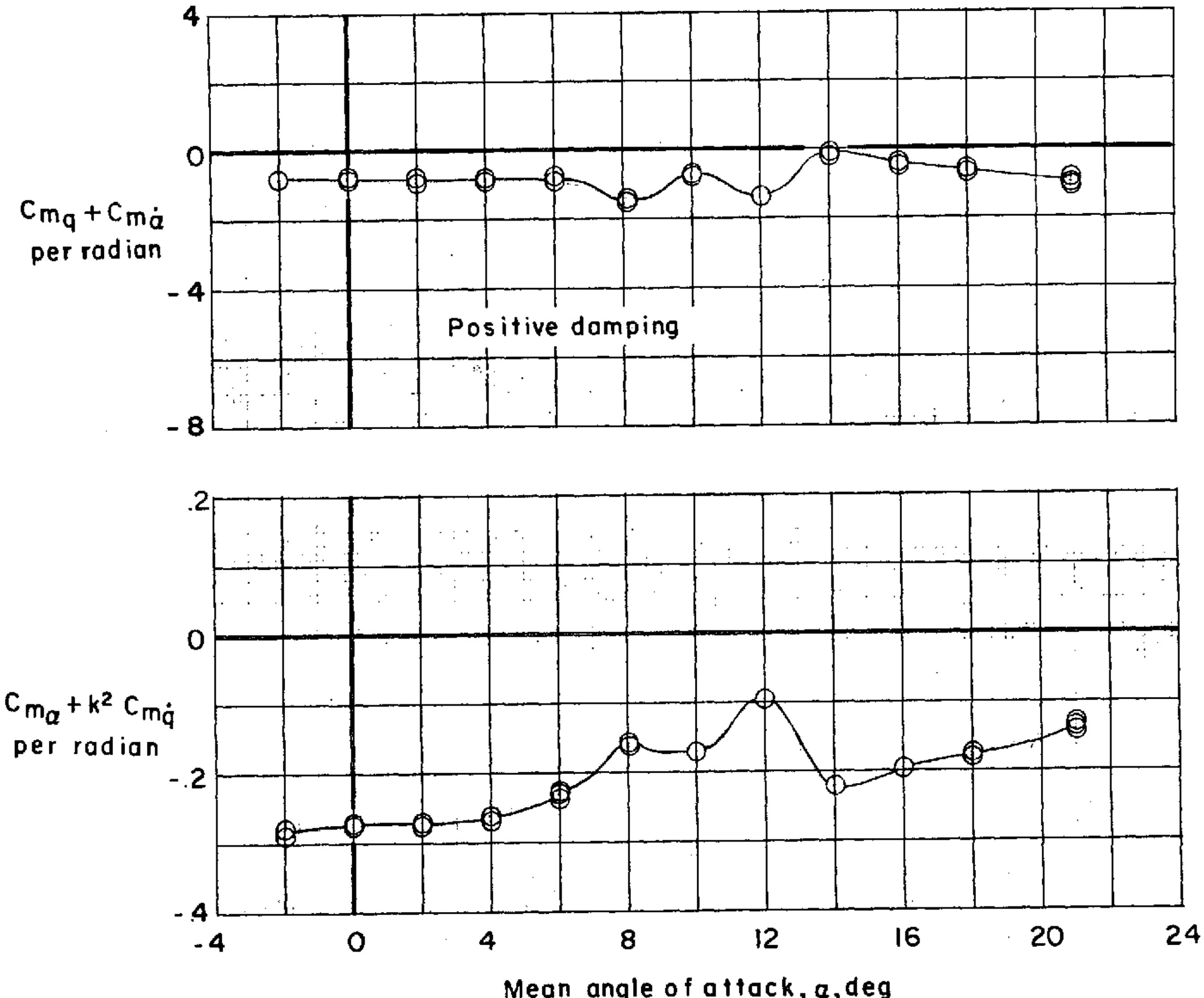
(e) $M = 0.90$, $R = 3.50 \times 10^6$, $k = .0114$ to $.0257$

Figure 5.- Continued.



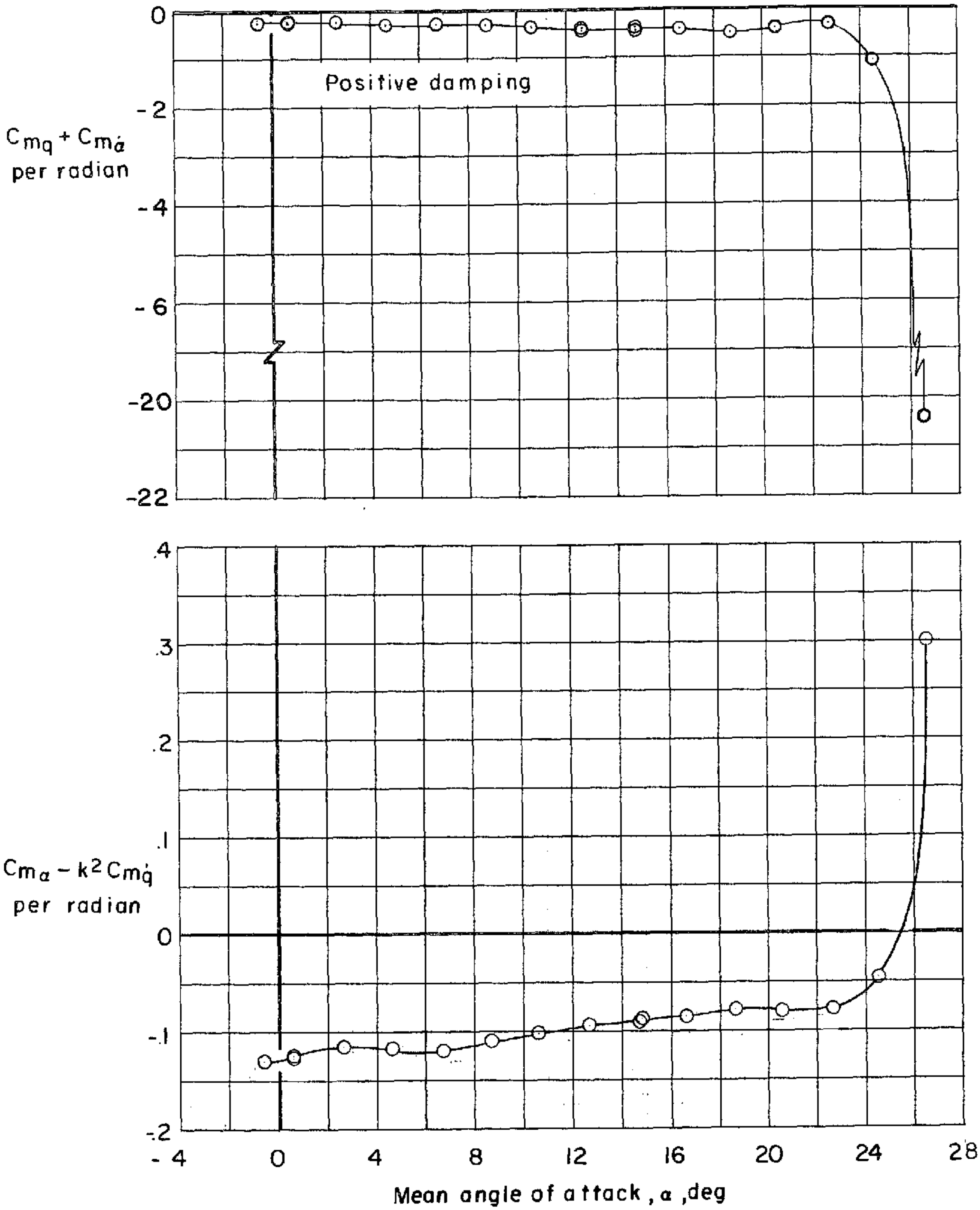
(f) $M = 1.00$, $R = 3.42 \times 10^6$, $k = .0180$ to $.0223$

Figure 5.- Continued.



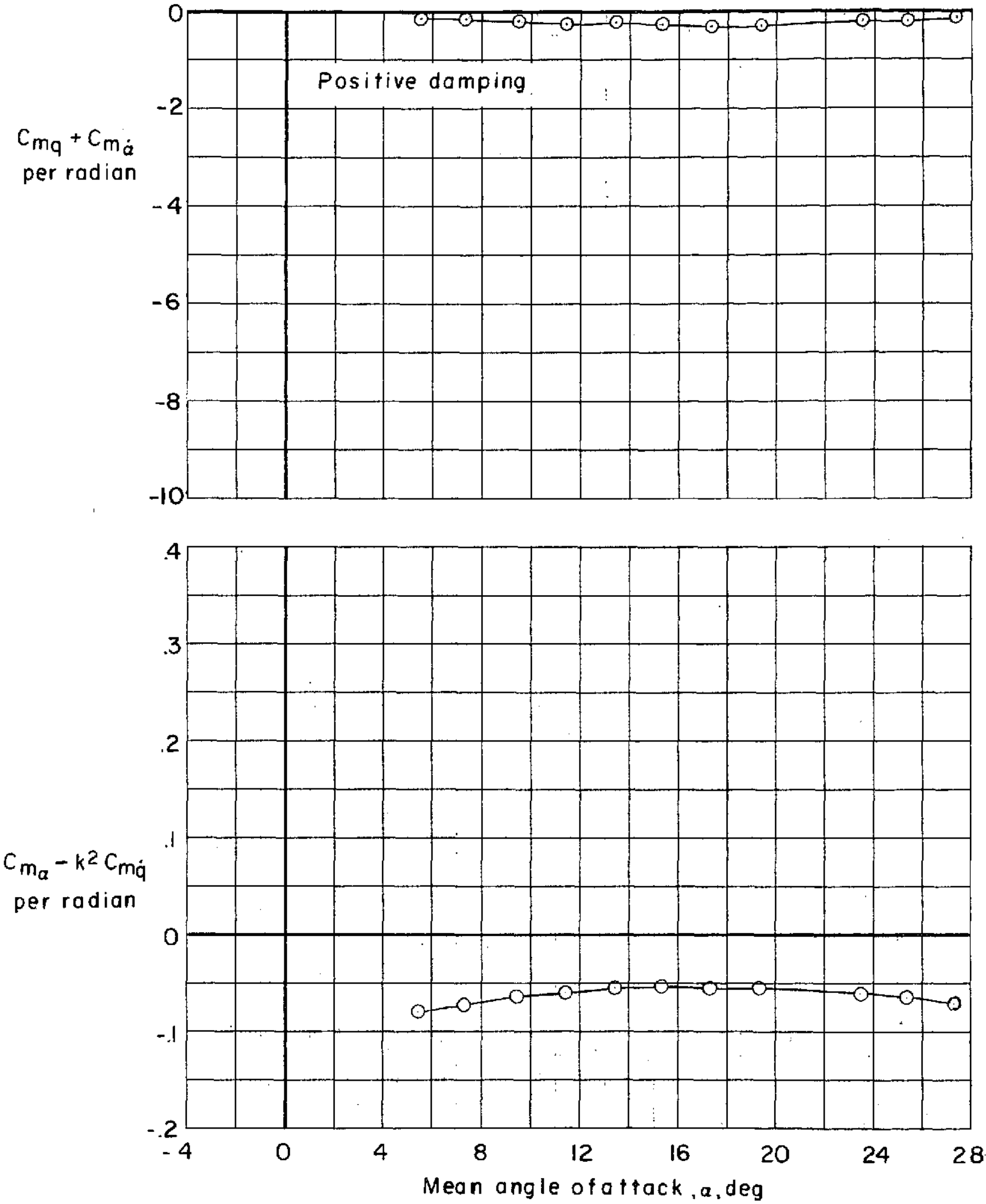
(g) $M = 1.20$, $R = 3.42 \times 10^6$, $k = 0.0158$ to $.0201$

Figure 5.- Concluded.



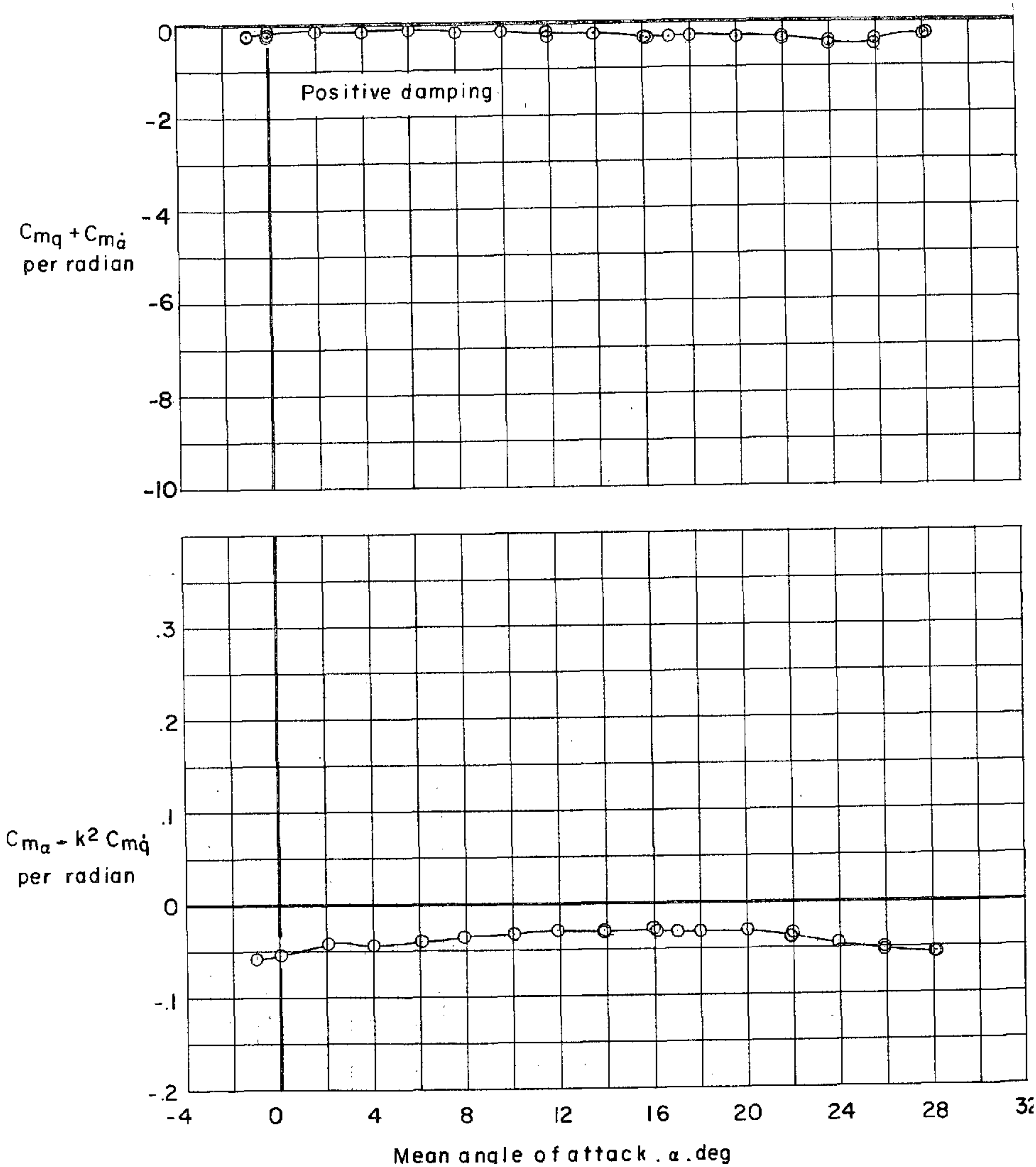
(a) $M = 1.80$, $R = 2.91 \times 10^6$, $k = .0102$ to $.0246$

Figure 6.- Variation of damping-in-pitch and oscillatory-longitudinal-stability parameters with mean angle of attack for a model of a proposed HL-10 configuration for Mach numbers of 1.80, 2.16, and 2.86.



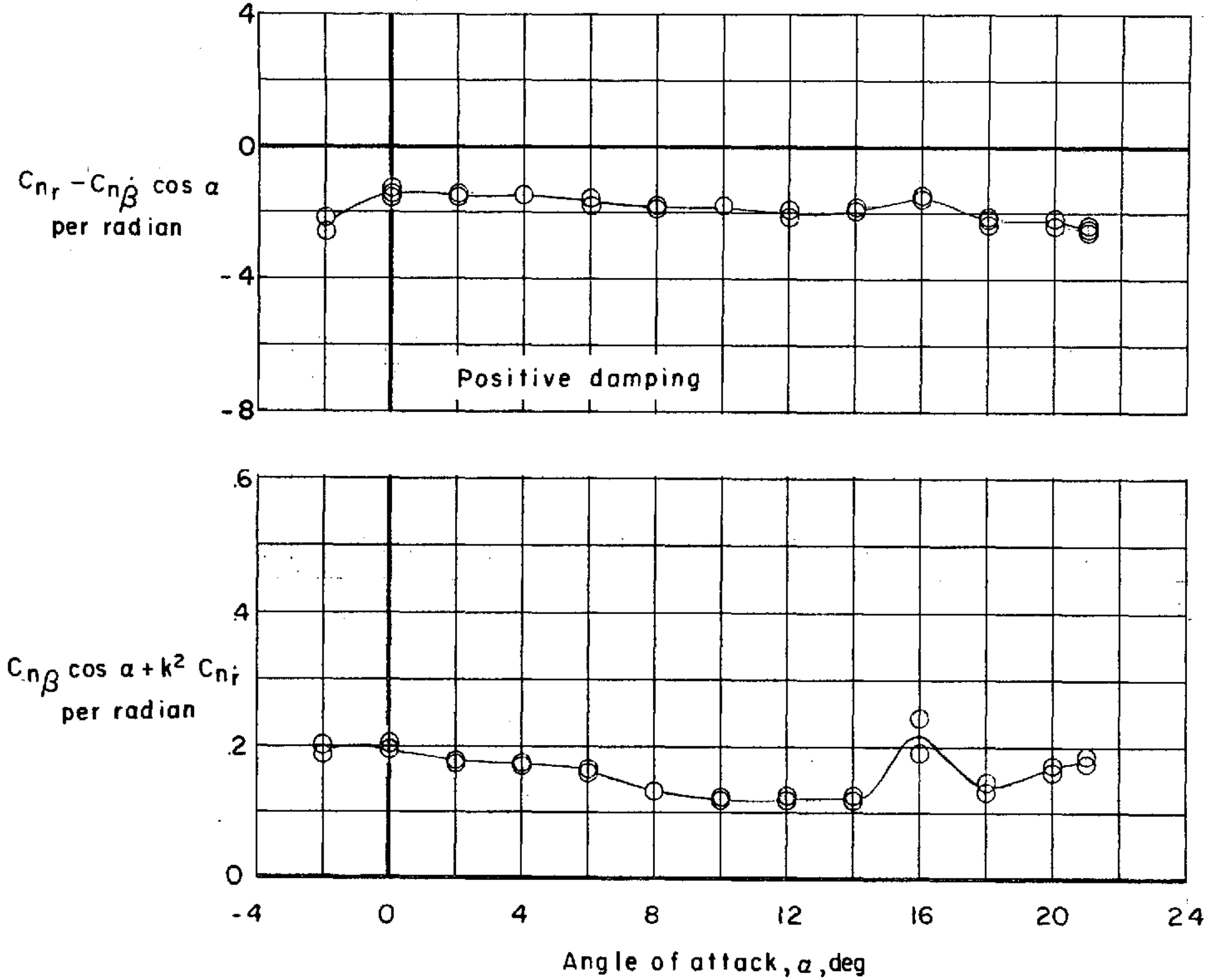
(b) $M = 2.16$, $R = 2.87 \times 10^6$, $k = .0193$ to $.0204$

Figure 6.- Continued.



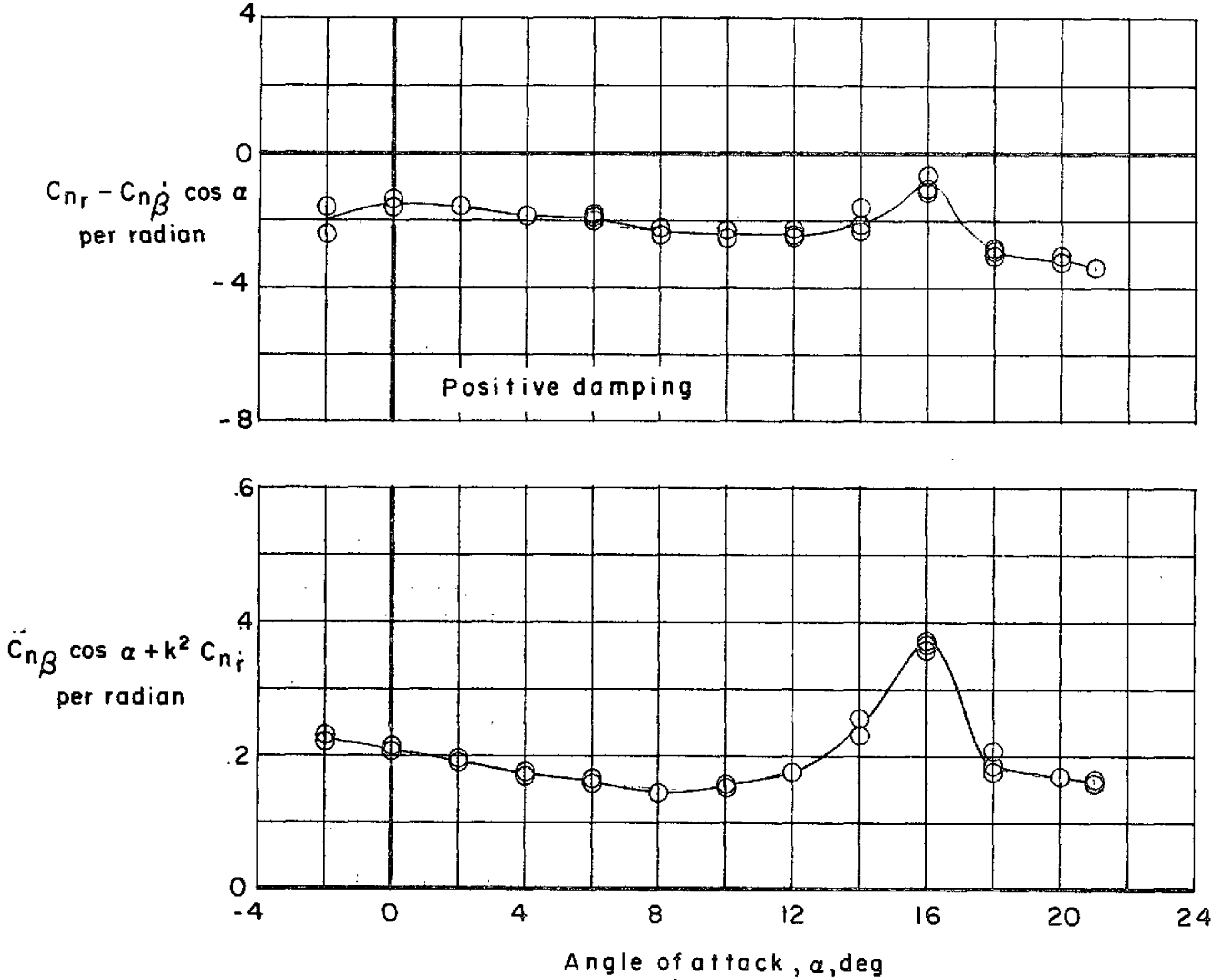
(c) $M = 2.86$, $R = 2.86 \times 10^6$, $k = .0163$ to $.0173$

Figure 6.- Concluded.



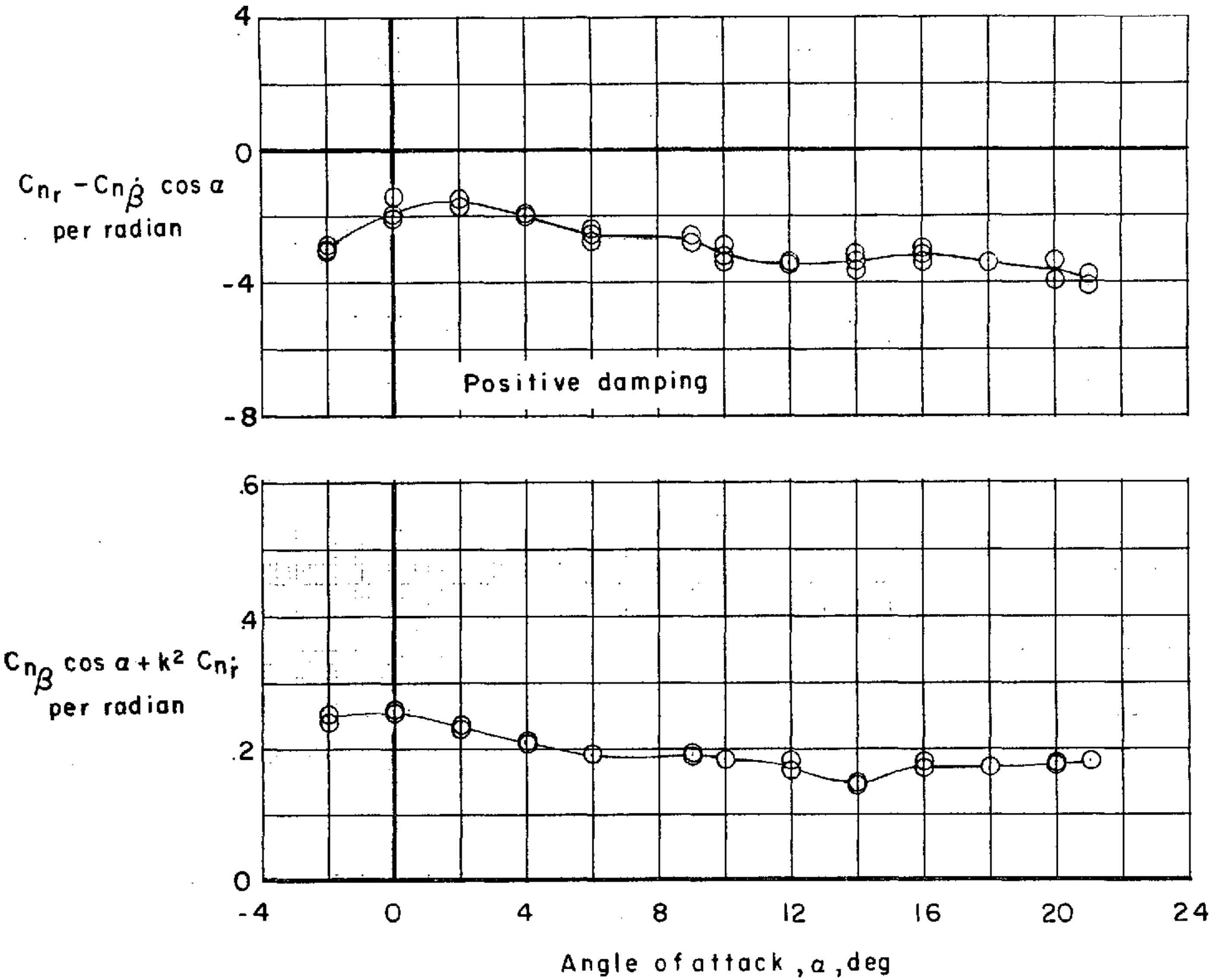
(a) $M = 0.20$, $R = 3.35 \times 10^6$, $k = .0420$ to $.0438$

Figure 7.- Variation of damping-in-yaw and oscillatory-directional-stability parameters with angle of attack for a model of a proposed HL-10 configuration at Mach numbers from 0.20 to 1.20.



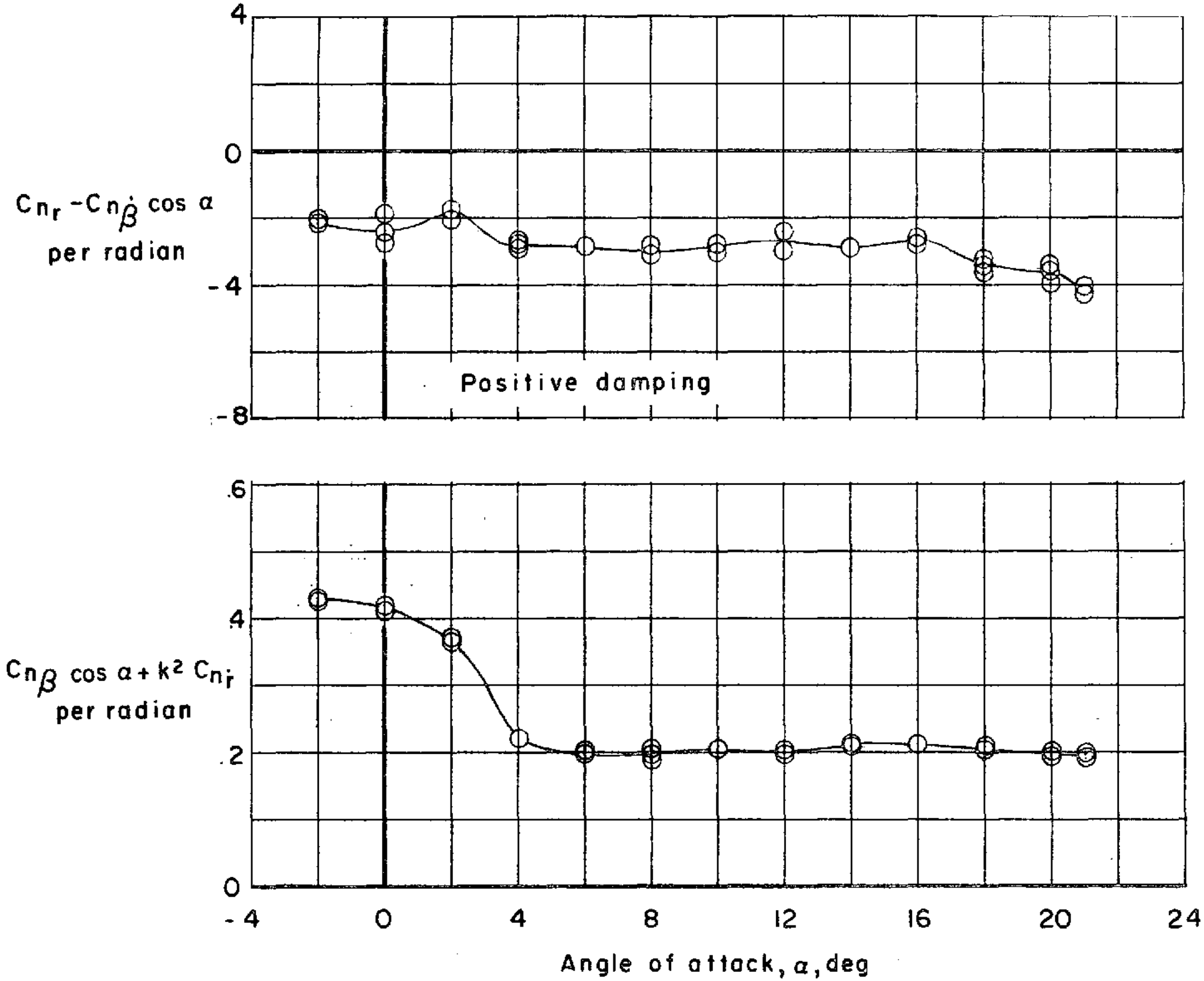
(b) $M = 0.40$, $R = 3.38 \times 10^6$, $k = .0222$ to $.0247$

Figure 7.- Continued.



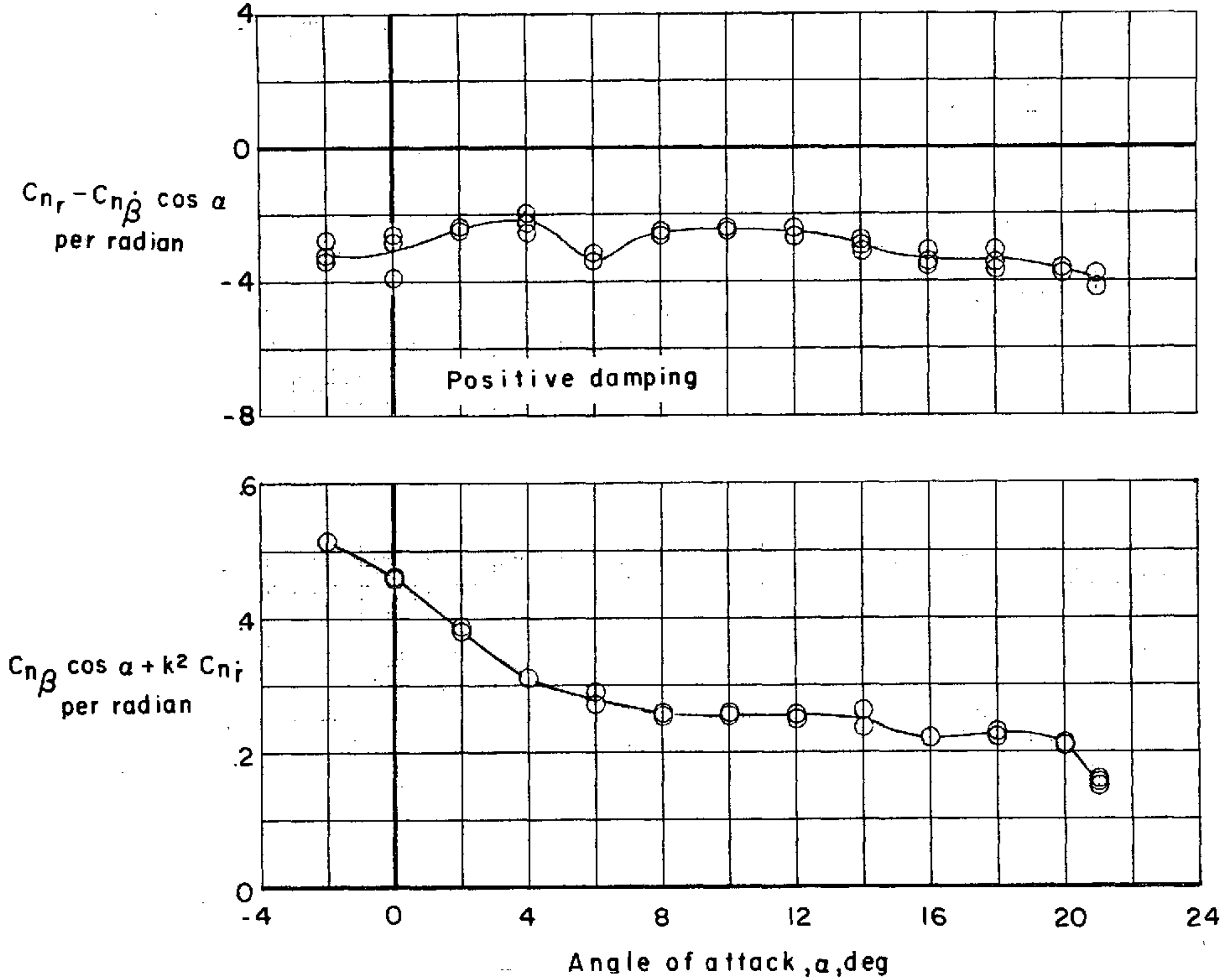
(c) $M = 0.60$, $R = 3.48 \times 10^6$, $k = .0156$ to $.0169$

Figure 7.- Continued.



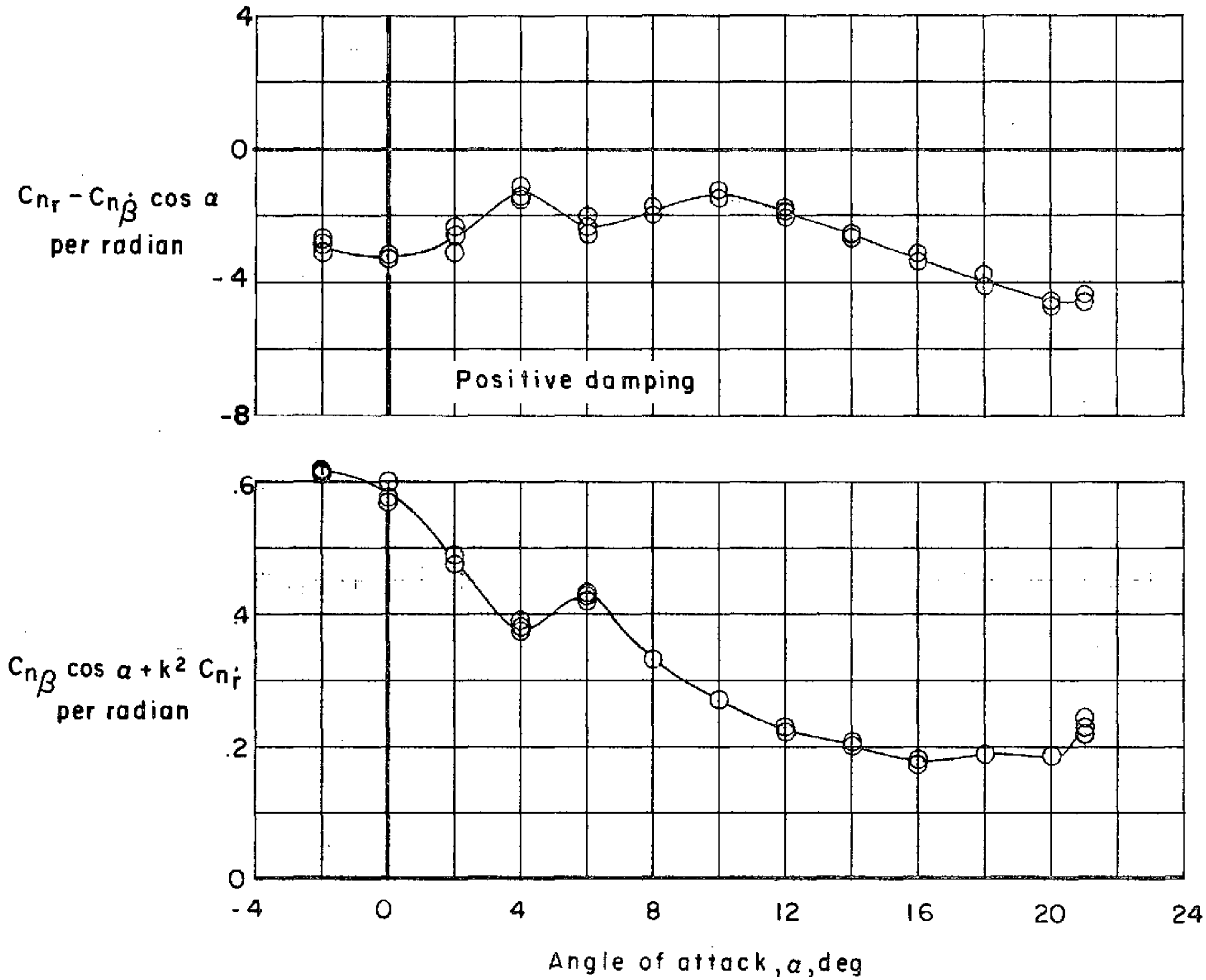
(d) $M = 0.80$, $R = 3.45 \times 10^6$, $k = .0152$ to $.0178$

Figure 7.- Continued.



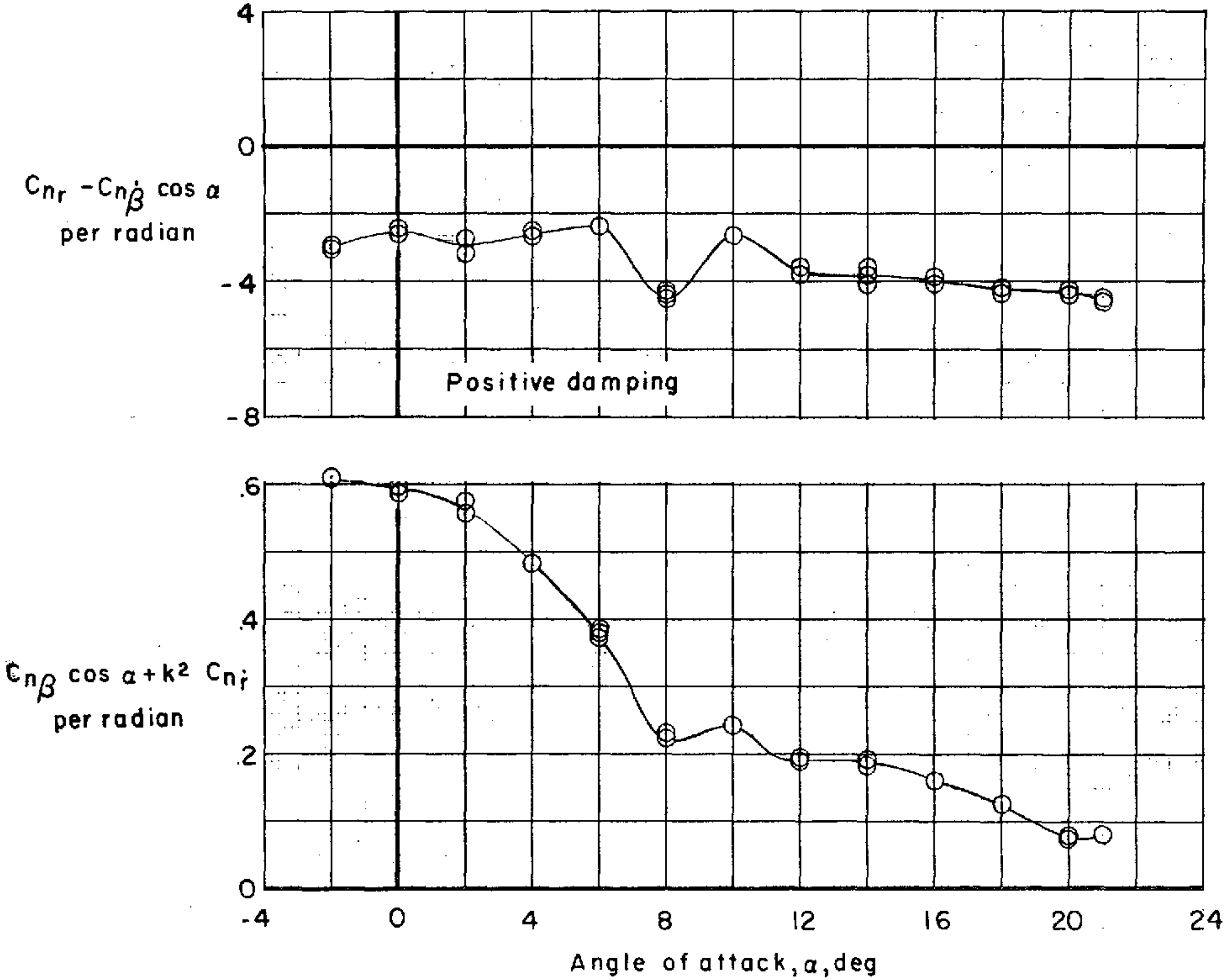
(e) $M = 0.90$, $R = 3.50 \times 10^6$, $k = .0114$ to $.0146$

Figure 7.- Continued.



(f) $M = 1.00$, $R = 3.42 \times 10^6$, $k = .0107$ to $.0143$

Figure 7.- Continued.



(g) $M = 1.20$, $R = 3.42 \times 10^6$, $k = .0084$ to $.0128$

Figure 7.- Concluded.

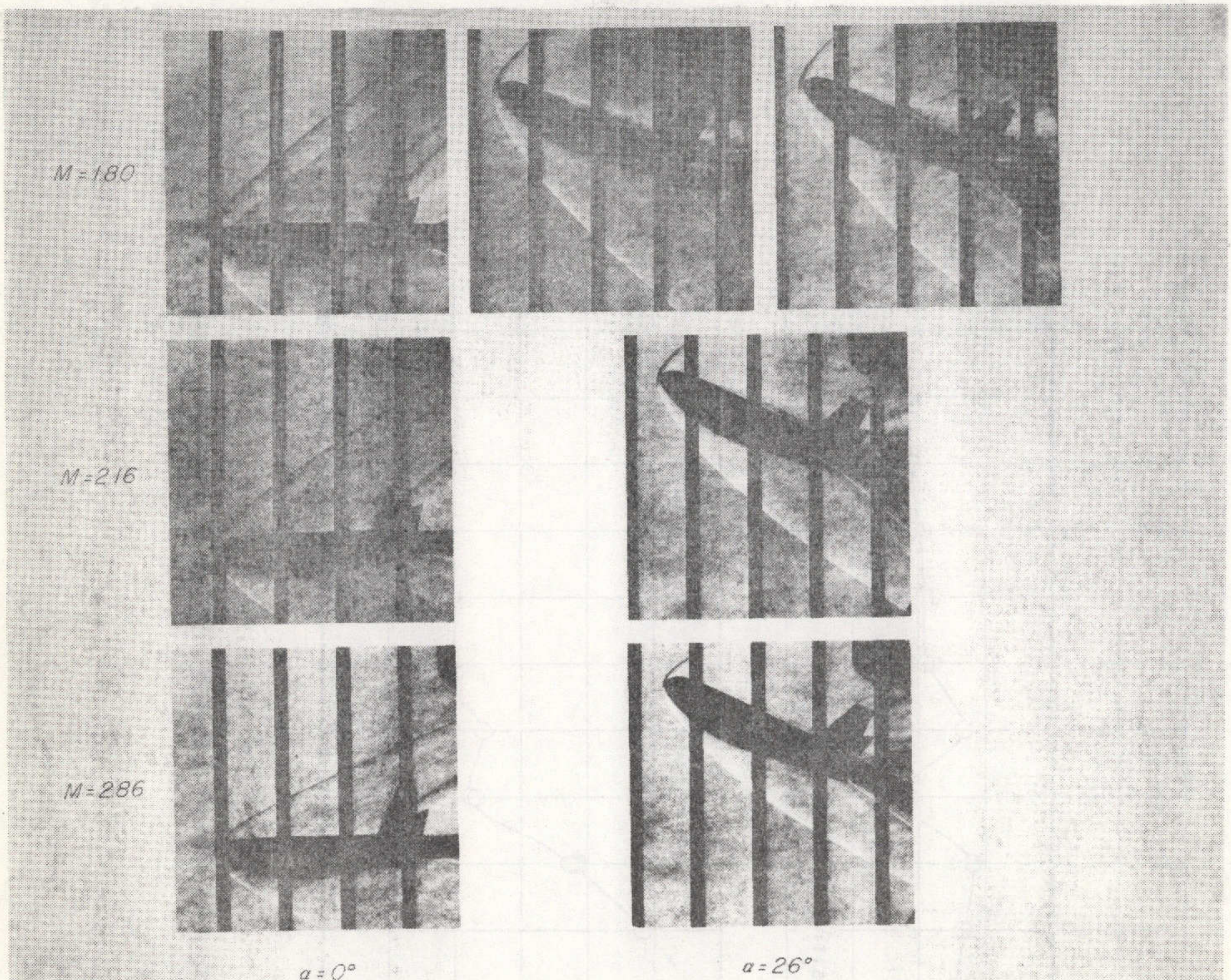


FIGURE 8. - SCHLIEREN PHOTOGRAPHS OF HL-10 CONFIGURATIONS.